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RESULTS OF TESTS ON A CHUTE WITH A ST. ANTHONY FALLS STILLING BASIN

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RESULTS OF TESTS ON A CHUTE WITH A ST. ANTHONY FALLS STILLING BASIN[1]

By William O. Ree, hydraulic engineer, Division of Drainage and Water Control, Research, Soil Conservation Service

CONTENTS

	Page
Introduction	1
Design and construction	1
Tests	3
Analyses and results	8
Conclusion	13

INTRODUCTION

This chute structure is located at the Stillwater Outdoor Hydraulic Laboratory of the Soil Conservation Service, Stillwater, Okla. Its primary function is to discharge the waste water from the laboratory into Stillwater Creek. The chute must safely convey 175 cubic feet per second through a drop of 10.8 feet. However, it has also served as an experimental structure, and it was designed and constructed partly with this purpose in mind. Figure 1 is a view of the chute from the lower end while it was discharging 168 cubic feet per second. Figure 2 is a view of the entrance during this same test flow.

The experiments on the chute were made over a period of 2 years. The first tests were made in the fall of 1949; these were repeated in 1950. A test consisted of passing a steady flow through the chute and observing the hydraulic behavior during the test flow. After the flow through the chute ceased, observations were made of the scour below the stilling basin. The test flows used in these experiments ranged from 22 to 168 cubic feet per second.

DESIGN AND CONSTRUCTION

Hydraulic Design

The design of the entrance of the chute is based on the report on flume entrances by Blaisdell and Huff.[2] The Wisconsin-type entrance chosen for the chute has a curved entrance section with a radius equal to the width of the chute, in this case 6 feet $9\frac{1}{2}$ inches. The floor curves at a radius of 28.79 feet. This curved portion joins the level entrance with the 2:1 sloping chute. The entrance head and the water-surface profile through the structure were estimated from the data given in the report mentioned above.

The chute terminates in a stilling basin patterned on the St. Anthony Falls Stilling Basin, the dimensions of the basin being exactly in accordance with the design rules developed by Blaisdell.[3] The Froude number of the flow entering the basin was calculated from

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[1]Prepared under the direction of Lewis A. Jones, chief, Division of Drainage and Water Control, Soil Conservation Service, Research, U. S. Department of Agriculture.

[2]Blaisdell, F. W., and Huff, A. N. REPORT ON TESTS MADE ON THREE TYPES OF FLUME ENTRANCE. U. S. Dept. Agr. Soil Conserv. Serv. SCS-TP-70, 26 pp., illus. 1948. /Processed./

[3]Blaisdell, F. W. THE SAF STILLING BASIN. U. S. Dept. Agr. Soil Conserv. Serv. SCS-TP-79, 14 pp., illus. 1949. /Processed./

FIGURE 1.--View of L2A chute structure discharging 168 c. f. s. The gage recording the entrance head is in the corrugated pipe shown at the upper right.

FIGURE 2.--Approach channel to chute structure L2A. Curvature of the approach results in a piling up of the water at the right wing wall.

the depth and velocity indicated by the estimated profile. In order to establish the elevation of the floor of the basin, it was necessary to determine the elevation in discharge relationship of the creek immediately below the basin. This was done by passing five measured flows ranging from 25 to 125 cubic feet per second down the creek. When the flow became steady, the elevation of the water surface at the control point was measured. The resulting rating curve is shown in figure 3. Figure 4 is a dimension sketch of the final design.

Structural Design

The chute and basin are constructed of reinforced concrete. The concrete used has a compressive strength of 3,000 pounds per square inch. The structural design was made in accordance with usual design practice. A contraction joint was provided at the junction of the chute and the basin. French drains were provided under the chute and along the walls. These drains discharge into a tile line which discharges through a weep hole in the wing wall. A shallow cut-off wall was provided at the downstream end. Although this low wall may seem inadequate, Blaisdell's report indicated that very little cut-off was needed, and in any event the chute is under frequent observation and needed repairs can readily be made. Figure 5 shows the detailed design of the structure.

Construction

The construction of the basin was difficult since it was necessary to excavate nearly 2 feet below the creek bottom in order to get sufficient tail-water depth for the basin. This required constant pumping and adequate shoring. The material on which the basin rests is a firm clay except at the south corner, where there was a deposit of sand and organic matter. Because of this, five small piles were driven beneath each basin wall. The subgrade was then covered with about 4 inches of crushed rock fill and the concrete base was then poured.

TESTS

As previously stated, the tests consisted of passing steady flows through the structure and measuring the hydraulic characteristics. In addition, the scour below the stilling basin was observed after each flow. The first series of tests was run in 1949. Although good data were obtained, the tests were repeated in 1950 because (1) a higher discharge rate was possible, and (2) the entrance channel to the chute had been improved. The changes in the entrance channel provided a more symmetrical flow.

The discharge rates used in the various chute experiments were as follows:

Experiment No. 1:	C. f. s.
Test No. 1	22.5
2	160.0
3	90.0

Experiment No. 2:	C. f. s.
Test No. 1	21.8
2	44.5
3	91.0
4	137.0
5	168.0

Views of test 5 during experiment 2 are shown in figure 6.

The observations made during these tests included the following:

1. Discharge rate Q, in cubic feet per second
2. Head-water elevation
3. Tail-water elevation
4. Water-surface profile in chute

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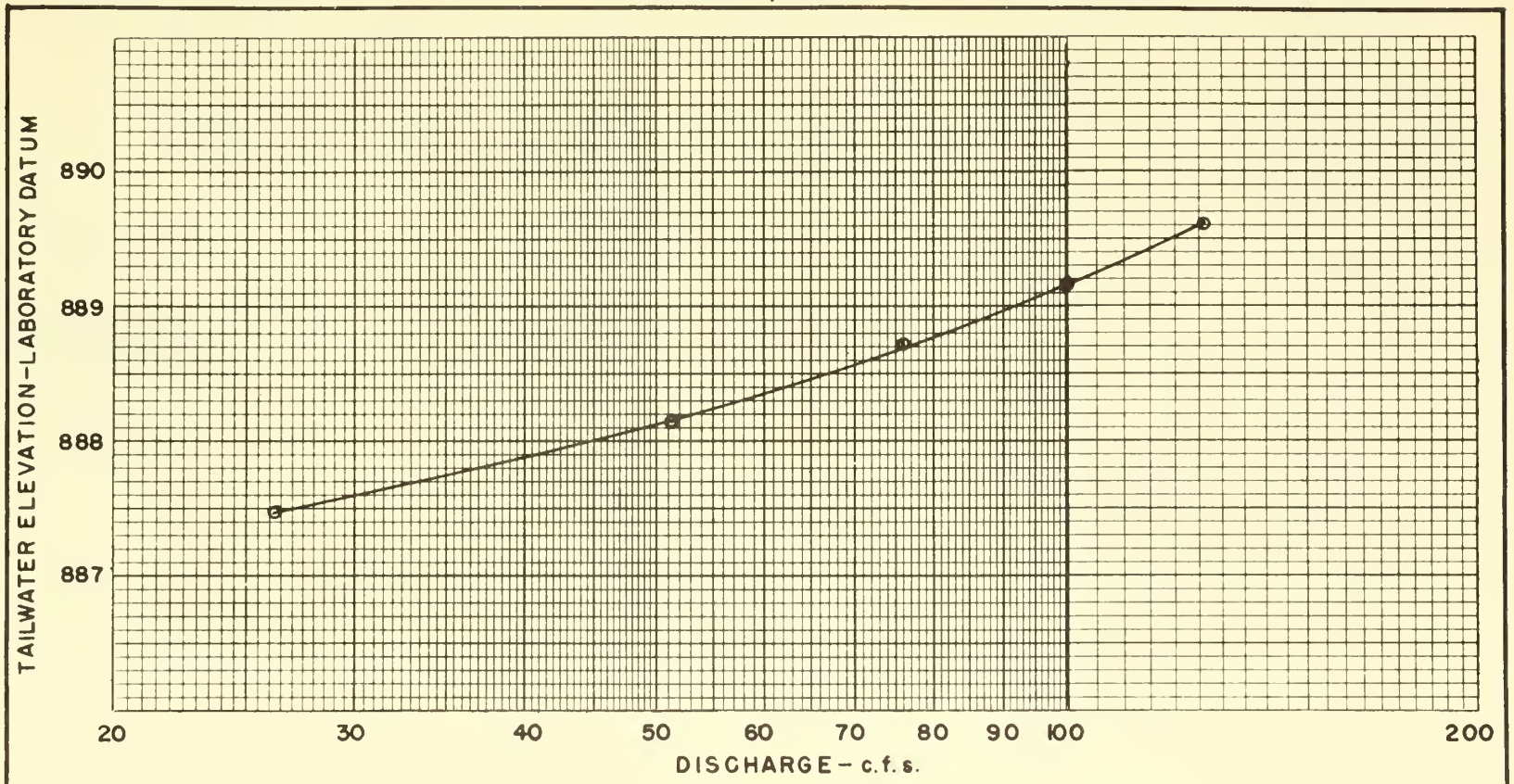

FIGURE 3.--Discharge-elevation relationship
Stillwater Creek below L2AF chute.

STILLWATER OUTDOOR HYDRAULIC LABORATORY

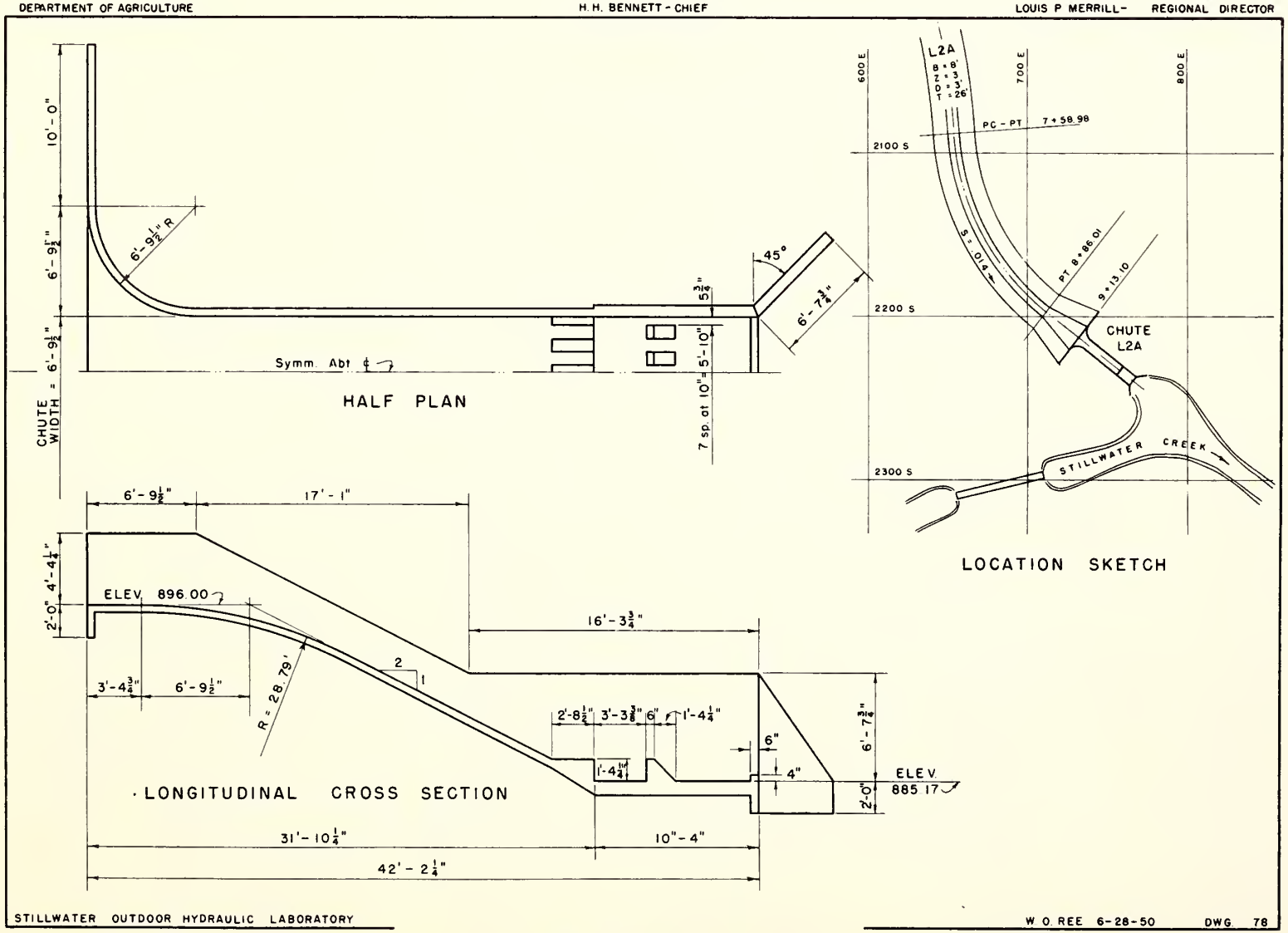

FIGURE 4.--Chute L2A.

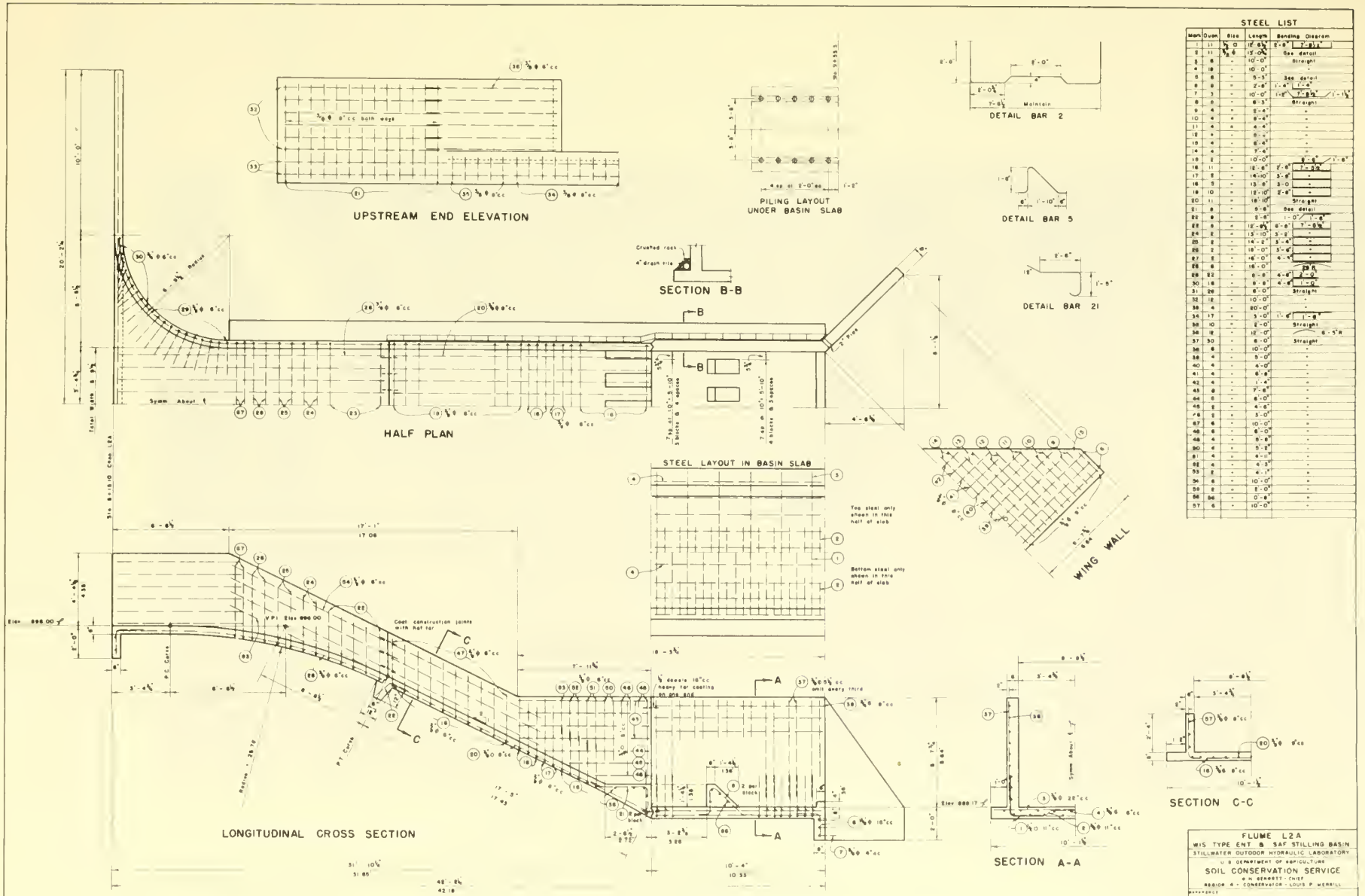

FIGURE 5.--Details of design of chute structure.

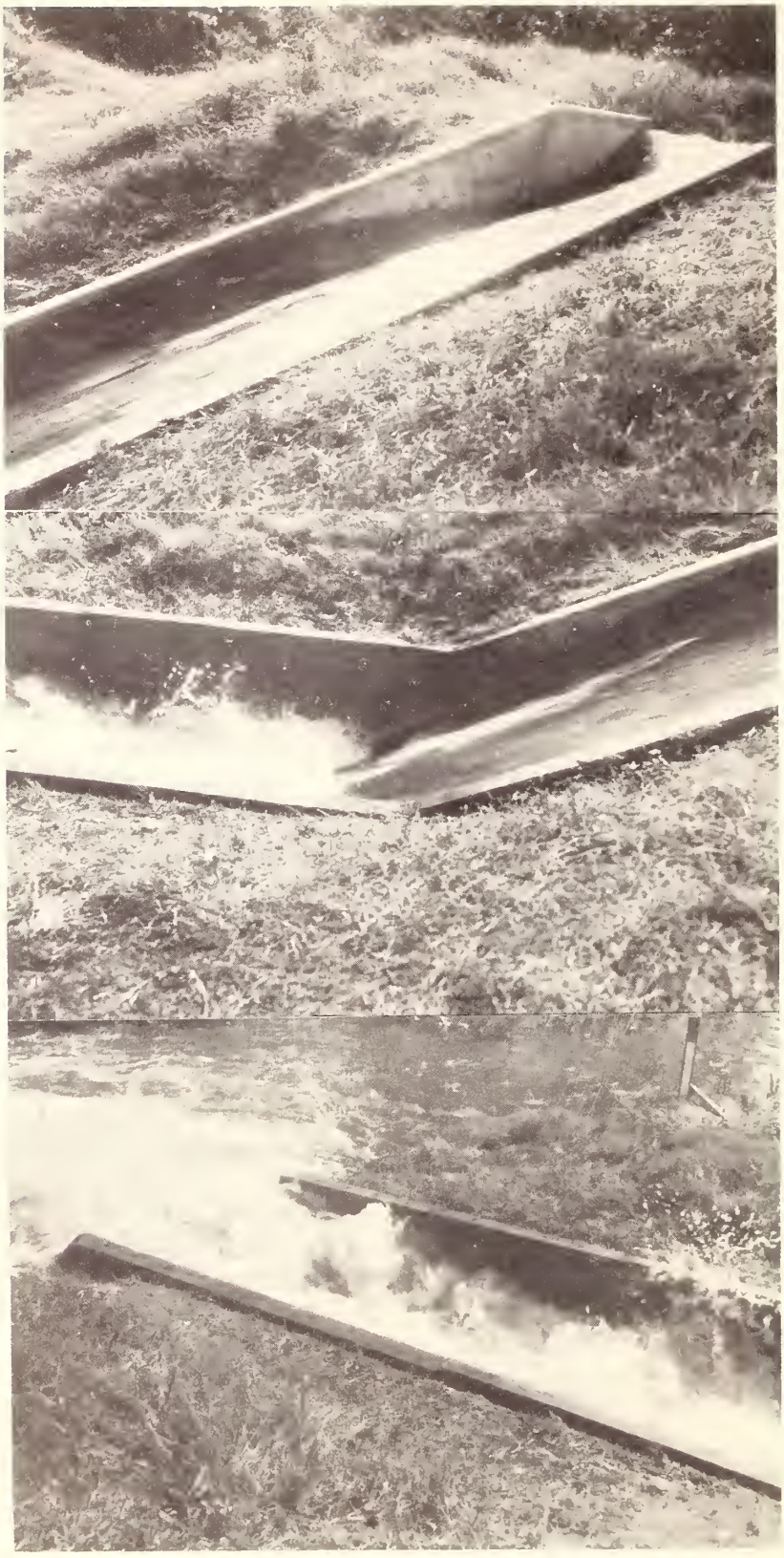

FIGURE 6.--Water-surface profile at different points in chute structure during test 5: upper end of chute *(above)*, bottom of chute *(middle)*, and stilling basin *(below)*. The discharge rate is 168 c. f. s.

5. General hydraulic behavior
6. Scour below chute
7. Chute profile
8. Photographs

The discharge rates were measured by the weir at the siphon outlet works. Corrections for leakage losses in the canal were believed unnecessary. There was considerable storage in the conveying system between the weir and the chute. It was necessary to run the flow for some time before it became steady at the test structure. The head-water elevation was measured by means of a recorder and also by an engineer's level. The water-stage recorder also served to indicate the time when flow became steady. The tail-water elevation was determined by a staff gage previously placed in the creek below the structure. The water-surface profile in the chute was measured by the use of an engineer's level and special pointed level rods. Observations of the water surface were taken at five points across the chute at selected stations along its length. These stations were 1 foot apart near the entrance and exit and 2 feet apart in the middle portion of the chute. The general observations of hydraulic behavior included such items as water temperature, duration of the test flow, presence of waves, point of start of jump, splash, excess turbulence, and related phenomena. All of these observations with the exception of time and temperature were made by visual inspection.

The scour below the chute, which was measured in detail only after the large test-flow run of 1949, was nearly negligible. In subsequent tests, scour was determined by visual inspection and by prodding with a probe to locate any deep scour pockets.

Profile measurements of the floor of the chute were carefully made in 1949 and again in 1950 by use of the engineer's level.

ANALYSES AND RESULTS

The first step in the analysis of the data was to reduce all readings to elevations. The water-surface profiles were plotted and compared with estimated profiles. Figure 7 shows the comparison between the actual and estimated profiles for test 5, experiment 2. At first glance, the small difference noted in the two profiles for this test may seem insignificant; and, in fact, the difference would have no effect on required wall heights for the chute section. However, since the Froude number is calculated from the estimated profile and the design of the stilling basin depends on the Froude number, an error can make considerable difference in the design of the basin. The comparison between the estimated and actual dimensions of the stilling basin is illustrated in table 1.

TABLE 1.--*Comparison of estimated and actual depths in chute for flow of 168 cubic feet per second*

Dimension	Estimated	Actual
d_1	1.20	1.00
V	20.60	24.75
d_2	5.1	5.6) Calculated requirements
d'_2	4.9	5.3) from initial depth and velocity

Errors in the determination of d'_2 can have serious effects. In this case the required depth based on the estimated profile was 4.9 feet whereas the plot of the actual profile

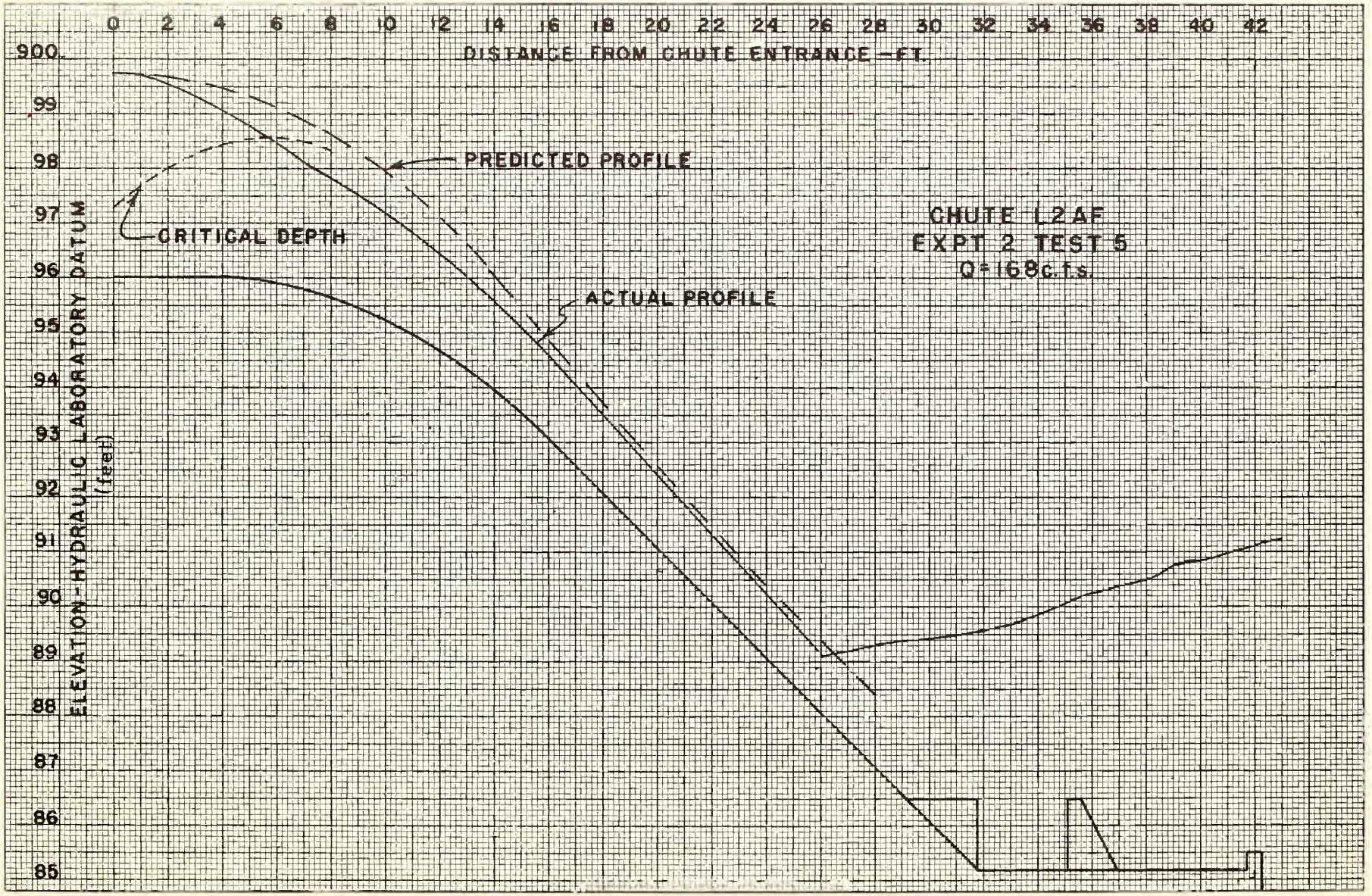
DISTANCE FROM CHUTE ENTRANCE—FT.
0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30 32 34 36 38 40 42
ELEVATION-HYDRAULIC LABORATORY DATUM (feet)
900 99 98 97 96 95 94 93 92 91 90 89 88 87 86 85
PREDICTED PROFILE
CRITICAL DEPTH
ACTUAL PROFILE
CHUTE L2AF
EXPT 2 TEST 5
Q=168c.f.s.

FIGURE 7.--Relation between actual and estimated water-surface profiles.

indicated the need for 5.3 feet. Fortunately, the stilling basin floor had been set low enough so there was sufficient tail water to allow satisfactory performance of the basin.

Since the estimate of depth and velocity of the flow jet entering the stilling basin is important, another approach was made to this problem; namely, computing a flow profile through the chute structure based on use of a friction formula. To obtain information for this method, values of Manning's n for different sections of the chute for the various tests were computed. This required a determination of the energy-line elevation during the test flow. The total energy at any point in the flow is given by the expression: energy = bottom elevation + $y \cos^2\theta + \frac{V^2}{2g}$;

where y = the vertical depth

θ = the angle between the vertical and a perpendicular to the floor of the chute

V = the velocity in a direction parallel to the floor of the chute

g = the acceleration of gravity

The total energy was computed for each observed station and the points plotted. These plottings are shown in figure 8. It will be observed that the plotted points were somewhat scattered, the variations probably being due to the difficulty of obtaining precise measurements on the turbulent water surface. Also, because of the very steep grade of the chute, any slight deviation of the level rod from the vertical or from the horizontal, could result in considerable error. A smooth line was drawn through scattered points. The slope of this line was then assumed to be the energy gradient to be used in the 4-foot reaches starting with station 8. The results are presented in tables 2 and 3. It will be observed that although there is considerable variation in the values of Manning's n for the different tests, the values tend to increase with the flow and decrease with the distance along the chute. This indicates that Manning's n reflects energy losses due to excess turbulence in addition to friction losses. However, it is unnecessary to determine the magnitudes of these losses separately; and the computed n values, reflecting total losses, serve as fair values in computing water-surface profiles.

A comparison of the elevations of the chute floor and stilling basin for 1949 and 1950 (table 4) shows there was no change in the position of any part of the structure from one year to the next. This was not only good evidence of the quality of the construction but also showed that the measurements were unaffected by any settling of the stilling basin.

As previously noted, only one complete set of scour measurements was made. Subsequent measurements were by visual inspection and probing. These measurements disclosed one small hole (0.5 foot below flow level), located 2 feet downstream. A slight scour around the wing walls, believed due to the unsymmetrical characteristics of the exit channel, will probably cease with the cutting out of a good channel.

It was observed that the curved approach channel resulted in an unsymmetrical flow. During test 5, experiment 2, for example, the water stood nearly 6 inches higher on the outside of the curve than on the inside (fig. 2). This resulted in excess contraction in the throat section of the chute with resulting excess turbulence in the flow below. Observation of the splash at the lower end of the chute showed that drops of water sometimes rose 10 feet above the water surface in the stilling basin. However, the amount of water thus

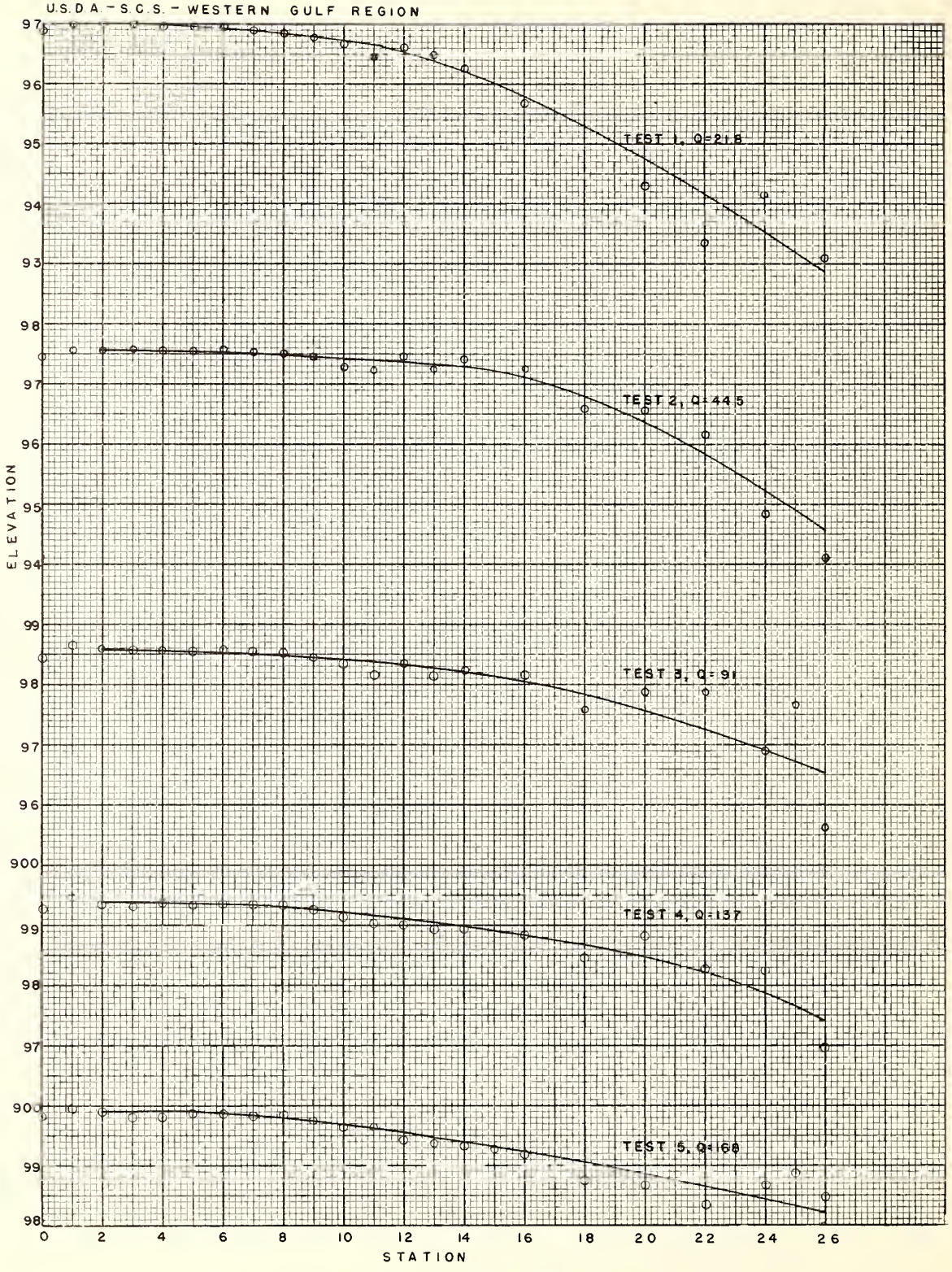

FIGURE 8.--Energy gradient, chute L2AF, experiment 2 February 2-28, 1951.

TABLE 2.--*Manning's n values for various reaches of chute*

Test No.	*Q*	Reach stations	Manning's *n*
	C. f. s.		
1	21.8	8 to 12	0.0256
		12 to 16	.0236
		16 to 20	.0204
		20 to 24	.0167
		Average	.0216
2	44.5	8 to 12	0.0180
		12 to 16	.0150
		16 to 20	.0182
		20 to 24	.0195
		Average	.0177
3	91.0	8 to 12	0.0238
		12 to 16	.0199
		16 to 20	.0192
		20 to 24	.0187
		Average	.0204
4	137	8 to 12	0.0303
		12 to 16	.0235
		16 to 20	.0190
		20 to 24	.0195
		Average	.0231
5	168	8 to 12	0.0323
		12 to 16	.0303
		16 to 20	.0222
		20 to 24	.0179
		Average	.0257

TABLE 3.--*Average Manning's n values for the chute*

Reach	Manning's *n*
8 to 12	0.0260
12 to 16	.0225
16 to 20	.0198
20 to 24	.0185

TABLE 4.--*Average elevations of chute and basin floor*

Station	1949	1950	Station	1949	1950
	Feet	*Feet*		*Feet*	*Feet*
0.....	96.03	96.01	16.....	93.06	93.07
1.....	95.98	96.00	18.....	92.06	92.07
2.....	96.01	96.01	20.....	91.08	91.09
3.....	96.02	96.01	22.....	90.08	90.09
4.....	96.02	96.01	24.....	89.06	89.06
5.....	95.98	95.97	26.....	88.01	88.03
6.....	95.90	95.89	28.....	87.04	87.05
7.....	95.78	95.77	30.....	86.00	86.04
8.....	95.63	95.63	32.....	85.17	85.18
9.....	95.45	95.45	34.....	85.21	85.18
10.....	95.22	95.21	36.....	85.16	85.17
11.....	94.94	94.94	38.....	85.16	85.17
12.....	94.66	94.66	40.....	85.16	85.18
13.....	94.31	94.31	41.....	85.16	85.17
14.....	93.94	93.95	42.....	85.49	85.49
15.....	93.54	93.53			

hurled up was small and most drops fell back into the basin.

CONCLUSIONS

Tests of the St. Anthony Falls Stilling Basin during a 2-year period at the Stillwater Outdoor Hydraulic Laboratory showed that the stilling basin was very effective and completely satisfactory. Very little scour of the channel bed occurred. It should be noted, however, that the bed material at the point of discharge was a rather firm clay. A sandy material might have shown a little different result.

The estimates of the water-surface profile were satisfactory for determining the chute-wall heights, but not for estimating the velocity and depth of the flow entering the basin. The latter estimates should be made on the basis of all data available, including observed profiles and the available Manning's n values.

Splash was not an important problem.

The construction costs were relatively high because of the need to place the stilling basin at a low elevation.